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Alleviation of cadmium (Cd) toxicity and minimizing its uptake in wheat (*Triticum aestivum*) by using organic carbon sources in Cd-spiked soil

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ABSTRACT

Cadmium (Cd)-contamination of agricultural soils has been receiving attention worldwide due to its entry into food crops such as wheat (*Triticum aestivum* L.). Little is known regarding the use of organic carbon (OC) sources in alleviating Cd toxicity in cereals. The current experiment was aimed to study the effects of different OC sources on the Cd accumulation by wheat. A pot study was conducted to determine the effects of rice husk biochar (RHB), farmyard manure (FYM), and lignite (LT) either alone or in combination on crop growth, Cd bioavailability and health risk assessment. The results proved that the application of OC sources like RHB, FYM, and LT either alone or in combination were highly effective in enhancing the wheat growth and yield as well as in minimizing the phyto-available fraction of Cd and its transfer to edible tissue of wheat. The RHB was the most efficient source in enhancing the plant growth and reducing the Cd concentration in wheat tissues. RHB increased grain yield by 91% and decreased Cd concentration in shoot, roots, grains, and bioavailable fraction of Cd by 67, 69, 62.5, and 74% than control, respectively. The RHB reduced the daily Cd uptake and health risk index in adults in comparison to control. Overall, where un-amended soil resulted in diminished plant productivity, the application of other OC sources also significantly proved their potential to enhance the dry weight and grain yield, suggesting that these OC sources may be used aiming to minimize the Cd concentration in crops. However, there is still a need to explore the potential of different OC sources in combination with other frequently available amendments for their large scale implementation in metal-contaminated soils.

1. Introduction

The main sources of toxic trace element accumulation in agricultural soils are both anthropogenic and geogenic activities which might be the main source of heavy metal transfer into food chain (Rizwan et al., 2016a; Rehman et al., 2015; Yin et al., 2016). Heavy metals are reported to cause toxicities in living things, mainly owing to their persistent and toxic and non-biodegradable nature in ecosystem (Bolan et al., 2014; Adrees et al., 2015a; Yousaf et al., 2016). Among the toxic heavy metals, cadmium (Cd) is one of the most hazardous element in environment (Nagajyoti et al., 2010; Rizwan et al., 2018). The main sources of Cd accumulation in agricultural soils are modern agricultural practices like application of raw industrial and municipal effluents, sewage sludges, phosphate fertilizer as well as mining waste incineration and atmospheric deposition (Murtaza et al., 2015; Qayyum et al., 2017). The main route of Cd entrance into plants is via the roots which could absorb the dissolved Cd in soil solution (Rizwan et al., 2016d). The reduction in root growth is the first toxic effect of Cd due to its direct contact with roots in the growth medium (Rizwan et al., 2016b). The Cd has been reported to cause the stunted plant growth, reduced photosynthesis as well as the yield and toxicity symptoms

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may also appear in plants such as chlorosis and browning of roots which depends upon the Cd concentrations present in the growth medium (Rizwan et al., 2017a). The Cd has also been shown to cause the accumulation of reactive oxygen species (ROS) in plants which ultimately disturbs several metabolic functions in plants (Rizwan et al., 2016b).

The consumption of cereal grains is the main route of toxic heavy metal entry to humans (Rizwan et al., 2016a; b). Among cereals, wheat (*Triticum aestivum* L.) is the most important crop which is mainly used as a staple food worldwide (Curtis and Halford, 2014). Globally, wheat is the 3rd most cultivated (218 million hectares) cereal crop after maize and rice, and it is positioned at 2nd number in terms of dietary intake. Wheat demand is rising at an alarming rate owing to the increase in world population as well as an increase in *per capita* consumption of wheat products (Curtis and Halford, 2014). Wheat has the higher ability of Cd accumulation and translocation as compared to other crops, which may enhance the Cd accumulation in wheat grains. The Cd uptake by wheat mainly depends on soil type, contamination level of soil and cultivars while Cd uptake by grains depends upon shoot-to-grain transfer and roots to grain via xylem-phloem loadings (Harris and Taylor, 2013). Therefore, it is mandatory to decrease the Cd accumulation in grains and ultimately in humans to reduce the Cd-mediated health risks to the general population.

A large number of techniques have been considered for the reduction of heavy metal uptake by numerous plant species at various levels, such as hydroponics, pots and field applications (Adrees et al., 2015b; Ali et al., 2015; Khaliq et al., 2016; Yousaf et al., 2017). Among several amendments, various organic amendments are previously employed aiming to decrease the metal uptake by plants and enhancing soil properties (Bian et al., 2014; Rehman et al., 2017). Organic treatments have been preferred over inorganic ones due to their higher biodegradability and environment friendly nature along with other numerous benefits (Rizwan et al., 2016c). Among various organic amendments, biochar is an organic material, which is produced mainly from crop byproducts under the limited oxygen supply at a defined temperature and time (Rizwan et al., 2016c). Literature has showed that biochar could be used for the immobilization of toxic trace elements in soil which is mainly due to the unique properties of biochar as compared to other organic materials such as surface area, high porosity, functional groups, cation exchange capacity (CEC) and pH (Rizwan et al., 2016c; Abbas et al., 2017). Biochar application in soil may increase the soil organic carbon (OC) and other mineral nutrients which may enhance soil fertility and increase crop growth depending upon the soil types, rate of application of biochar, and plant species (Abbas et al., 2017).

Similarly, other frequently available organic amendments could also be used for reducing of metal uptake by plants (Yousaf et al., 2017; Etesami, 2018; Rehman et al., 2018). For this purpose, the raw organic materials like farmyard manure (FYM), and lignite (LT) have become a striking substitute to chemical amendments due to their high efficacy, and biodegradability (Rehman et al., 2016). The FYM could be employed in reducing metal uptake by plants which is mainly due to the nutrients present in the material that may compete with the heavy metals during their uptake at the surface of roots (Rehman et al., 2018). On the other hand, increasing attention is being focused on the use of industrial waste to remediate the Cd polluted soils and in this regard LT and fly ash are extensively considered as low cost heavy metal stabilizing agents. Lignite is the byproduct of the coal industry, produced through reductive decomposition. It is an extremely heterogeneous material having three-dimensional structure which contains more organic functional groups, mainly carboxyl groups (Kwiatkowska et al., 2008; Paramashivam et al., 2016). Few studies have reported the effect of LT on heavy metal uptake by plants (Simmler et al., 2013; Rehman et al., 2017).

To date, the effects of individual OC sources have been reported in the literature but less is known regarding the combined effects of various OC sources in the alleviation of Cd toxicity and its accumulation in plants. In addition, most of the organic amendments have been used based on their dry weight while little is known regarding the OC contents as the OC varies with the organic amendments. Thus, treatments from organic amendments such as biochar, FYM, and LT were calculated based on their OC contents and their effects on Cd uptake as well as on wheat growth and yield, were assessed in Cd-spiked soil. Overall, the main objectives of the present experiment were to: 1) compare the effects of various OC sources on wheat growth and yield; 2) determine the Cd translocation factor, translocation index, and harvest index; 3) assess the effects of OC sources on bioavailable Cd in soil, and 4) determine the health risk index of the Cd via consumption of wheat grains.

2. Material and methods

2.1. Soil sampling and analysis

Soil samples were taken from upper surface of soil (0–20 cm) from an agricultural field of the Institute of Soil and Environmental Sciences (ISES), University of Agriculture, Faisalabad (UAF), Pakistan. The samples were spread over a plastic sheet at ambient room temperature under shade for air drying, then soil was crushed and sieved from 2 mm sieve. The samples were analyzed for particle size classes (Bouyoucos, 1962) using hydrometer and pH was measured using a pH meter (HM-12P, Korea). The electrical conductivity (EC) was measured using 0.01 N KCl calibrated conductivity meter (Sensodirect Con 200s-Lovibond, England) (Richards, 1954). The soluble ions and sodium adsorption ratio (SAR) were determined by standard protocols (US Salinity Laboratory Staff, 1954; Page et al., 1982). The organic carbon contents were measured through Walkley–Black method (Walkley and Black, 1934) and phytoavailable metal ion were measured through ammonium bicarbonate-diethylene triamine pentaacetic acid (AB-DTPA) extraction (Soltanpour, 1985) using 20 ml of AB-DTPA (0.005 M DTPA + 1 M NH_4CO_3 having a pH of 7.6) in 10 g dried sieved soil. The atomic absorption spectrometer (AAS) (SolarS-100, Thermoelectron, USA) was used to determine metal concentration in soil extract. The initial selected characteristics of soil are given in Table 1.

2.2. Collection and preparation of soil amendments

Three organic amendments evaluated in this experiment were:

Table 1
Physiochemical properties of soil used in study.

Soil Characteristics	Before contamination	After contamination
Textural class	Sandy loam	–
Saturation (%)	30.86	–
pH_s	7.79	7.74
EC_e (dS m^{-1})	1.97	2.80
TSS ($mmol_c$ L^{-1})	19.70	28.00
CO_3^{-2} ($mmol_c$ L^{-1})	Absent	Absent
HCO_3^- ($mmol_c$ L^{-1})	2.24	2.21
Cl^- ($mmol_c$ L^{-1})	5.92	6.88
$Ca^{2+} + Mg^{2+}$ ($mmol_c$ L^{-1})	14.48	16.34
SO_4^{-2} ($mmol_c$ L^{-1})	11.54	18.91
Na^+ ($mmol_c$ L^{-1})	5.22	6.51
SAR (mmol L^{-1})$^{1/2}$	1.94	4.09
OM (%)	0.65	0.65
AB-DTPA Ext. Cd (mg kg^{-1})	0.049	12.73